PARENTAGE AND TYPE OF PLANTING STOCK INFLUENCE BIOMASS CHARACTERISTICS IN SYCAMORE PLANTATIONS 1/

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ABSTRACT.--Green volumes, green weights, and dry weights were determined for above-ground component parts of sycamore tees in a five-year-old progeny test in northeast Mississippi. Three types of planting stock were used to establish each of ten families in the test: (i) top cuttings from seedlings, (ii) top-pruned seedlings, and (iii) whole seedlings. Trees established from top cuttings had lower volumes, weights, stem and crown dimensions, and survival than did those from whole or top-pruned seedlings. Top-pruned seedlings produced significantly less dry weight per acre than did whole seedlings. Families differed for volumes and weights, but not for distribution of dry matter among the above-ground components. Implications for establishment of sycamore energy plantations and genetic improvement programs are discussed.

American sycamore (*Platanus occidentalis* L.) exhibits rapid early growth. Consequently, the species has received considerable interest for use in short-rotation plantations for energy or wood fiber. Assessments of biomass production in these plantations are needed to compare the species with other forest and agronomic crop species. Biomass in the present paper represents the above-ground phytomass of the tree: leaves, limb wood, limb bark, stem wood, and stem bark.

Numerous investigations have indicated that biomass production per acre of sycamore plantation is affected by tree spacing, age at harvest, cutting cycle in coppice management, and fertilization (Kennedy 1975, Saucier et al. 1972, and Wood et al. 1976). Nothing has been reported, however, about the influence of parentage or type of planting stock on the distribution and amount of above-ground biomass in sycamore. The objectives of the present study were to determine (i) family and planting-stock effects upon component biomass and (ii) the implications of such effects upon genetic improvement strategies and establishment of energy plantations.

MATERIALS AND METHODS

Ten open-pollinated families and three planting-stock types were used. The ten families came from eight geographic seed sources in the Gulf South (Fig. 1), with two families per source being used from sources 'A' and 'F' and a single family per source representing the other six sources. Types of planting stock were (i) unrooted top cuttings from 1-0 seedlings, (ii) top-pruned 1-0 barerooted seedlings, and (iii) whole 1-0 barerooted seedlings. Seedlings were cut at one inch above the root collar to provide a complete top cutting and a detopped root system, and these were planted as the first two planting-stock types.

The study was planted on a river bottom site in Oktibbeha County, Mississippi (33° 18' north, 88° 55' west) in June 1974. A split plot design was used, with whole units (families) arranged as randomized complete blocks in four replications. The three types of planting

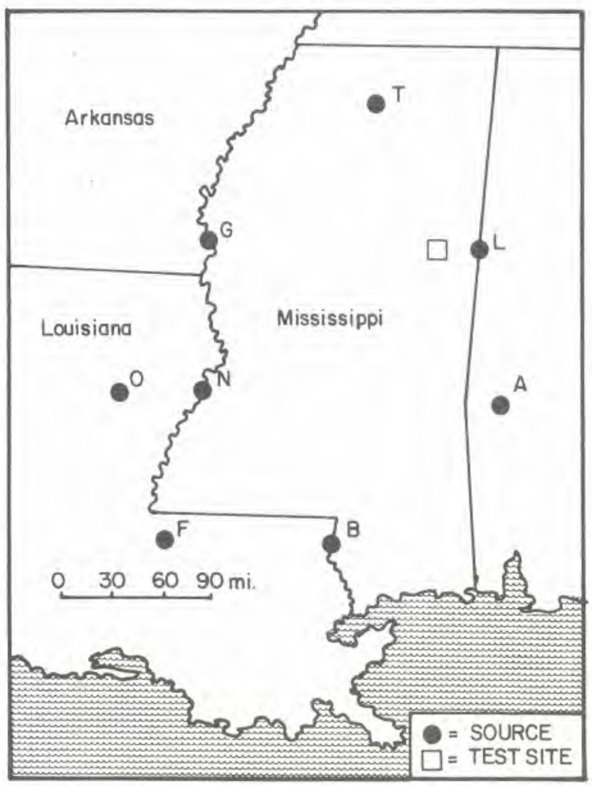

Figure 1. Geographic locations of seed sources and test site for a sycamore progeny test used to study effects of parentage and type of planting stock on biomass characteristics of five-year-old trees.

stock comprised the subunits, and each subunit plot consisted of five propagules. Six-hundred propagules were planted for measurement, and a single border row surrounded the study. Trees were spaced at ten feet by ten feet within plots, and the plantation was disced each year during the first three years.

In the winter of 1978-79, after five growing seasons in the field, measurements were taken of diameter outside bark at a six-inch stump height, diameter at breast height (DBH), total stem height, live crown length, number of multiple stems arising from within six inches above the ground, and survival.

Fifty-four trees representing six of the ten families, the three types of planting stock, and three of the four replications were destructively sampled during the summer of 1979. The same standing-tree measurements as were recorded the previous winter were taken on these 54 trees before they were cut. Each tree was cut at a six-inch stump height, and green weight was obtained for each of the following components: (i) leaves, (ii) stem above a six-inch-high stump, and (iii) living limbs. Samples collected per tree consisted of (i) 25 leaves from among all of the leaves collected, (ii) two stem discs, each one-inch thick, at four-foot intervals up the tree from one-half foot to a 241/2-foot maximum height, and (iii) five to fifteen limb sections, each one-inch long, with the number of sections being dependent on the range in limb sizes present. Limb and stem samples were separated into wood and bark components and measured for green weight and green volume. Leaf samples were weighed for green weight. Oven-dry weights were obtained after drying at 105° C for 28 hours. Weighted dry weight/green weight ratios and green volume/green weight ratios from the samples were used to calculate whole tree values for oven-dry weights and green volumes of stem wood, stem bark, limb wood, limb bark, and leaves.

Prediction equations relating green volume, green weight, and oven-dry weight to standing-tree measurements were determined by regression procedures using data from the 54-tree sample. These equations were applied to all 600 trees in the study to predict values from tree measurements taken in the winter of 1978-79. Since four plots were missing at age five, least-squares analysis with unequal subclass numbers (Harvey 1975) was used to test significance of variation in the 600-tree study. Duncan's New Multiple Range Test was employed to test differences among ranked means.

Thirty-six trees were randomly selected from among the remaining trees in the study in September 1979 and March 1980, and leaf, limb, and stem samples were collected for determination of caloric contents. No identification was maintained on family, replication, or type of planting stock for each tree. Sampling procedures were the same as described above, and lab procedures for determination of caloric contents were those described by Neenan and Steinbeck (1979).

RESULTS

Volume and Wei:ht Relationships of Sample Trees

The trees sampled for volume and weight relationships averaged 3.1 inches DBH and 26 feet total height (Table 1). Live crowns extended nearly to the ground and averaged 23.6 feet in length. Approximately one-half of the above-ground green volume, green weight, and oven-dry weight was in stem wood. Limb wood comprised the next largest component.

Table 1. Means and ranges for traits of sample trees in the five-year-old sycamore progeny test.

Trait	54-Tree Sample Mean	Minimum	Maximum
Standing-Tree Parameters:			
Diameter at a 6-inch Ht. (in.)	4.1	2.6	5.7
DBH (in.)	3.1	2.0	4.4
Total Height (ft.)	26.0	19.5	34.5
Live Crown Length (ft.)	23.6	11.7	32.4
Green Volume (cu.ft./tree):			
Stem Wood	0.63	0.20	1.24
Stem Bark	0.08	0.02	0.20
Limb Wood	0.34	0.03	0.65
Limb Bark	0.06	0.01	0.14
Total	1.10	0.27	2.20
Green Weight (lbs./tree):			
Stem Wood	45.7	12.2	94.7
Stem Bark	4.7	1.8	8.6
Limb Wood	21.2	1.4	41.7
Limb Bark	4.3	0.5	9.7
Leaves	19.2	1.9	33.6
Total	95.0	17.8	178.2
Oven-Dry Weight (lbs./tree):			
Stem Wood	20.6	5.3	36.1
Stem Bark	1.9	0.8	3.6
Limb Wood	9.8	0.6	19.4
Limb Bark	1.8	0.2	3.0
Leaves	6.7	0.7	17.0
Total	40.7	7.7	72.5
Dry Weight Distribution (% of total):			
Stem Wood	50.7	44.7	69.3
Stem Bark	4.9	3.7	10.4
Limb Wood	23.6	8.3	32.2
Limb Bark	4.3	2.6	6.2
Leaves	16.5	9.2	26.9

Table 2. Means and tests of significance for effects of planting-stock type on five-year-old sycamore trees used in the 54-tree sample.

Trait	Means & Tests of Significance[a/] for Types of Planting Stock: Cutting	Seedling: Top-Pruned	Seedling: Whole
Standing-Tree Parameters:			
Diameter at a 6-inch Ht. (in.)	3.6 a	4.5 b	4.3 b
DBH (in.)	2.8 a	3.3 b	3.3 b
Total Height (ft.)	24.6 a	26.8 b	26.6 b
Live Crown Length (ft.)	21.6 a	24.8 b	24.5 b
Green Volume (cu.ft./tree):			
Stem Wood	0.47 a	0.73 b	0.69 b
Stem Bark	0.06 a	0.08 b	0.09 b
Limb Wood	0.23 a	0.39 b	0.39 b
Limb Bark	0.05 a	0.07 b	0.07 b
Total	0.81 a	1.27 b	1.24 b
Green Weight (lbs./tree):			
Stem Wood	34.2 a	53.2 b	49.5 b
Stem Bark	3.7 a	5.3 b	5.1 b
Limb Wood	14.8 a	24.2 b	24.6 b
Limb Bark	2.9 a	4.9 b	5.2 b
Leaves	14.5 a	22.0 b	21.0 b
Total	70.1 a	109.7 b	105.4 b
Oven-Dry Weight (lbs./tree):			
Stem Wood	15.5 a	23.7 b	22.4 b
Stem Bark	1.5 a	2.2 b	2.1 b
Limb Wood	6.9 a	11.0 b	11.6 b
Limb Bark	1.3 a	1.9 b	2.1 b
Leaves	5.0 a	7.1 b	7.9 b
Total	30.1 a	45.9 b	46.2 b
Dry Wt. Distribution (% of total):			
Stem Wood	52.3 b	51.2 ab	48.8 a
Stem Bark	5.1	4.8	4.6
Limb Wood	21.9 a	24.0 ab	24.8 b
Limb Bark	4.2	4.2	4.6
Leaves	16.5	15.8	17.2

a/ Means not followed by the same letter for a given trait are significantly different at the .05 probability level. Where no letters are present, none of the means are significantly different.

Trees grown from seedling-top cuttings had significantly smaller standing-tree parameters, volumes and weights than trees from top-pruned or whole seedlings (Table 2). Top-pruned and whole seedlings were not significantly different. Type of planting stock had a small, but significant, effect on dry matter distribution. Trees developed from seedling top-cuttings had a greater proportion of the total dry weight in the stem wood and less in the limb wood than trees from whole seedlings. Top-pruned seedlings were intermediate and not significantly different from either cuttings or whole seedlings.

Limb wood volume and limb bark volume differed significantly among some families, but green weight, oven-dry weight, and dry matter distribution did not differ (Table 3). There were no significant interactions between families and types of planting stock.

Table 3. Family means and significance tests of family differences for standing-tree parameters, volumes, and weights of sycamore trees used in the 54-tree sample.

Trait	Means & Tests of Significance [a/] for Families [b/]					
	A1	B1	F1	F2	G1	O1
Standing-Tree Parameters:						
Dia. at a 6-inch Ht. (in.)	3.8	4.3	4.3	4.1	4.5	3.9
DBH (in.)	2.9	3.3	3.3	3.1	3.3	3.0
Total Height (ft.)	26.3	27.0	25.6	25.6	26.1	25.5
Live Crown Length (ft.)	24.0	24.3	23.5	23.6	23.3	23.0
Green Volume (cu.ft./tree):						
Stem Wood	0.57	0.68	0.68	0.61	0.71	0.54
Stem Bark	0.07	0.07	0.09	0.08	0.10	0.06
Limb Wood	0.27 a	0.35 ab	0.38 b	0.36 ab	0.37 b	0.29 ab
Limb Bark	0.05 a	0.06 ab	0.07 b	0.07 b	0.06 ab	0.05 ab
Total	0.95	1.16	1.21	1.11	1.24	0.95
Green Weight (lbs./tree):						
Stem Wood	41.0	49.3	48.2	42.7	52.9	39.9
Stem Bark	4.0	4.9	5.3	4.8	5.1	4.1
Limb Wood	17.5	22.6	23.3	22.4	23.3	17.9
Limb Bark	3.3	4.8	4.6	4.9	4.5	3.7
Leaves	17.1	21.0	20.8	18.8	20.2	17.2
Total	83.0	102.6	102.2	93.6	106.1	82.7
Oven-Dry Weight (lbs./tree):						
Stem Wood	18.9	22.3	21.8	19.8	22.3	18.2
Stem Bark	1.6	2.0	2.2	1.9	2.1	1.6
Limb Wood	8.1	10.9	10.5	10.9	10.4	8.1
Limb Bark	1.5	1.9	1.7	2.0	1.8	1.6
Leaves	5.8	7.8	7.4	6.2	6.8	6.1
Total	35.9	44.8	43.6	40.7	43.5	35.7
Dry Wt. Distribution (% of total):						
Stem Wood	52.1	49.8	50.3	48.3	52.8	51.2
Stem Bark	4.7	4.5	5.2	4.6	5.4	4.7
Limb Wood	22.3	24.3	23.3	26.8	22.4	22.2
Limb Bark	4.2	4.2	4.0	4.9	4.1	4.5
Leaves	16.7	17.1	17.2	15.4	15.3	17.4

a/ Family means not followed by the same letter for a given trait are significantly different at the .05 probability level. Where no letters are present, none of the means are significantly different.

b/ The alphabetic first character in a family identification number refers to the seed source (Figure 1).

Equations for predicting volumes and weights of individual trees from standing-tree parameters were developed from the pooled 54-tree sample, since family differences were usually absent and variation among types of planting stock could be explained by differences in the parameters. Linear regression equations having (i) no intercept and (ii) the same tree parameter for all equations were desired in order to avoid negative predictions and to provide predicted component values that could be summed to equal the predicted total tree value. Basal area per tree (DBH^2) was consistently one of the best predictors, so that overall it ranked first as the single variable to use in all equations (Table 4). Biomass values for all trees in the 600-tree study were estimated from these equations.

Table 4. Equations for prediction of volumes and weights of above-ground components in trees of a five-year-old sycamore progeny test in northeast Mississippi.

Dependent Variable (=Y)	Prediction Equation [a]	$S_{y \cdot x}$
Green Volume (cu.ft./tree):		
Stem Wood	$Y = 0.0631(DBH)^2$	0.064
Stem Bark	$Y = 0.0078(DBH)^2$	0.024
Limb Wood	$Y = 0.0337(DBH)^2$	0.075
Limb Bark	$Y = 0.0059(DBH)^2$	0.017
Total	$Y = 0.1105(DBH)^2$	0.112
Green Weight (lbs./tree):		
Stem Wood	$Y = 4.6024(DBH)^2$	4.74
Stem Bark	$Y = 0.5674(DBH)^2$	0.519
Limb Wood	$Y = 2.1151(DBH)^2$	4.64
Limb Bark	$Y = 0.4317(DBH)^2$	1.26
Leaves	$Y = 1.8816(DBH)^2$	3.69
Total	$Y = 9.4982(DBH)^2$	8.20
Oven-Dry Weight (lbs./tree):		
Stem Wood	$Y = 2.0559(DBH)^2$	2.09
Stem Bark	$Y = 0.1905(DBH)^2$	0.204
Limb Wood	$Y = 0.9769(DBH)^2$	2.25
Limb Bark	$Y = 0.1720(DBH)^2$	0.412
Leaves	$Y = 0.6531(DBH)^2$	1.94
Total	$Y = 4.0484(DBH)^2$	4.72

[a] DBH = diameter in inches outside bark at breast height.

Table 5. Means and tests of significance for effects of planting-stock type on standing-tree parameters and above-ground dry weight yields in a five-year-old sycamore progeny test.

Trait	Means & Tests of Significance [a] for Types of Planting Stock: Cutting	Seedling: Top-Pruned	Seedling: Whole
Diameter at a 6-inch Ht. (in.)	3.0 a	3.[illegible] b	3.5 b
DBH (in.)	2.2 a	2.5 b	2.6 b
Total Height (ft.)	20.0 a	22.1 b	21.9 b
Live Crown Length (ft.)	18.2 a	20.6 b	20.4 b
Multiple Stems (%)	5.0 a	29.5 b	26.1 b
Survival (%)	54.0 a	89.5 b	97.5 b
$(DBH)^2$	4.93 a	6.83 b	7.17 b
Total Above-Ground Dry Wt. (tons/ac.)	2.3 a	5.4 b	6.2 c
Stem + Limb Dry Wt. (tons/ac./yr.)	0.39 a	0.90 b	1.04 c

[a] Means not followed by the same letter for a given trait are significantly different at the .05 probability level.

Yield Characteristics of the Total Study

Trees from seedling-top cuttings were smaller, had lower survival, had fewer multiple stems, had smaller basal areas per tree (DBH^2), and produced less dry matter per acre than trees from top-pruned or whole seedlings (Table 5). Component volumes, green weights, and dry weights would give the same results as DBH^2, since the predicted values for each component were derived from this parameter. Top-pruned and whole seedlings had similar sizes, survival, multiple stems, and biomass values per tree. However, whole seedlings produced significantly more dry matter per acre than top-pruned seedlings.

Families differed significantly in stem diameter, height, crown length, survival, volume per tree, green weight per tree, dry weight per tree, and dry matter production per acre, but not in percent

Table 6. Family means and significance tests of family differences for standing-tree parameters and above-ground dry weight in a five-year-old sycamore progeny test.

Trait	Means & Tests of Significance [a/] for Families [b/]									
	A1	A2	B1	F1	F2	G1	L1	N1	O1	T1
Dia. at 6-inch Ht. (in.)	3.3ab	2.8a	3.3ab	3.6b	3.4ab	3.5b	3.6b	3.1ab	3.0ab	3.6b
DBH (in.)	2.5b	2.0a	2.4ab	2.6b	2.5b	2.6b	2.6b	2.3ab	2.3ab	2.5b
Total Height (ft.)	24.1c	19.4a	20.1ab	21.8abc	21.2abc	22.4abc	21.8abc	20.0ab	19.5a	22.7bc
Live Crown Length (ft.)	22.3d	17.4a	18.5abc	20.7bcd	19.4abcd	21.0cd	20.1abcd	18.5abc	17.8ab	21.1cd
Multiple Stems (%)	24.6	11.6	22.1	22.2	20.4	28.2	19.1	12.1	19.2	22.9
Survival (%)	78.3abc	78.3abc	70.0ab	83.3abc	98.3c	91.7bc	78.3abc	76.7abc	80.0abc	68.3a
$(DBH)^2$	6.88ab	4.47a	6.00ab	7.12b	6.88ab	7.05ab	7.05ab	5.53ab	5.36ab	6.76ab
Tot. Above-Ground Dry Wt. (tons/ac.)	4.7abc	3.1a	3.7ab	5.2abc	6.0c	5.7bc	4.9abc	3.7abc	3.8abc	4.1abc
Stem + Limb Dry Wt. (tons/ac./yr.)	0.80abc	0.52a	0.62ab	0.88abc	1.00c	0.96bc	0.82abc	0.63abc	0.63abc	0.68abc

a/ Family means not followed by the same letter for a given trait are significantly different at the .05 probability level. Where no letters are present, none of the means are significantly different.

b/ The alphabetic first character in a family identification number refers to the seed source (Figure 1).

multiple stems (Table 6). Family 'F2' from a tree along the Mississippi River near St. Francisville, Louisiana, produced the greatest dry matter per acre, primarily because of its high survival combined with a moderately high dry weight per tree. Family 'A2' from a tree near the Tombigbee River at Butler, Alabama, had the smallest values for all traits except survival. No geographic patterns were evident among the family means. Interactions between families and types of planting stock were not significant.

Energy contents in BTU's per oven-dry pound of biomass were 8415 for leaves, 8080 for limb wood, 8338 for limb bark, 8080 for stem wood, and 8557 for stem bark. Multiplying these values by the oven-dry weights produced per acre provided the results in Table 7. Cuttings produced 38.5 million BTU's per acre, while whole seedlings produced 100.7 million. Family A2' yielded 50.4 million BTU's per acre, and Family F2' produced 97.4 million. These differences in energy yield were significant, since the dry weight yields were 'significantly different.

DISCUSSION

Volume and weight yields per acre were low when compared with other published reports for sycamore (Kennedy 1975, Saucier et al. 1972, and Wood et al. 1976). This difference is probably due to the wider spacing used in the present study than in those earlier studies. Wide spacing is appropriate when mechanical cultivation with large tractors and discs is necessary for weed control. It also allows easy access for mechanical thinning, where the plantation

Table 7. Oven-dry weight and energy yields per acre for various families and types of planting stock in a five-year-old sycamore progeny test.

Treatment	Total Above-Ground Portion of Trees	
	Oven-Dry Wt. (lbs./ac.)	Energy Content (million BTU's/ac.)
Study Mean	9030	73.7
Seedling-Top Cuttings	4700	38.5
Top-Pruned Seedlings	10780	88.0
Whole Seedlings	12330	100.7
Family 'A2' (lowest family)	6170	50.4
Family 'F2' (highest family)	11925	97.4
Top Cuttings from Family 'A2'	2295	18.7
Whole Seedlings from Family 'F2'	14280	116.5

is to be carried to a sawtimber rotation. However, ten-foot by ten-foot spacing does not maximize yields per acre for five-year rotations on the site tested, since the trees apparently have not fully occupied the site. This incomplete occupancy is indicated by the retention of live crowns nearly to the ground. Crown closure, which is sometimes used as a measure of full site occupancy, would have resulted in natural pruning of the lower limbs.

Another reason for low volume and weight yields per acre for the overall study was the poor survival and poor growth of seedling-top cuttings. This poor performance is largely due to the late planting date employed in the study. Cuttings planted in June would have little time to develop root systems before rapid summer transpiration rates and large water deficits occur. Evidently, late spring or summer plantings should use seedlings rather than cuttings.

It is often recommended that sycamore seedlings be top pruned at time of planting to reduce the transpiring surface area and thereby increase survival. Other factors may negate this advantage of reduced transpiration surface, however, as was apparently the situation in the present study. Dry weight yield per acre was one ton (15 percent) less from top-pruned seedlings than from whole seedlings. The difference between the two types of planting stock is probably an indirect result of differences in seedling heights above ground during the first year after establishment. The shorter top-pruned seedlings were more difficult to see during cultivation and, thus, more likely to be disced over or covered by sod than the taller whole seedlings. Furthermore, damage and suppression by competing vines and weeds were greater for the shorter top-pruned seedlings. Although survival and dry weight per tree were not significantly lower for top-pruned than whole seedlings, the product of the two in expanding to a per-acre basis certainly illustrates how important the disadvantage of shorter height can be. Whole seedlings should be preferred over top-pruned seedlings or unrooted cuttings for establishing plantations, particularly where heavy equipment will be used for cultivation and where large weed or vine problems exist.

The significant differences among families for tree size; survival, and dry matter yields per acre provide an opportunity for improvement in these traits through genetic selection and breeding. However, the lack of family differences in distribution of dry matter among the above-ground tree components is disappointing and contrary to results found for loblolly pine (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm.) by van Buijtenen (1978). Ideally, the tree breeder would like to have genetic variability both in total productivity and in distribution within the tree. He can then breed for varieties that grow fast and allocate more of the dry matter to the parts of the tree to be harvested. The present results indicate that breeding efforts for improvement of above-ground biomass production in sycamore should concentrate on survival and stem growth rate per tree. Improved growth of all components should result from such a program, since there were no differences between families in dry matter distribution among components. DBH will be an easy and important standing-tree parameter to measure in evaluating young progeny tests for rate of biomass growth per tree.

The above discussions and recommendations for establishment and genetic improvement of sycamore plantations hold equally for biomass yields or energy yields. Since little difference among families was found in dry matter distribution, the differences in energy contents from the various above-ground components cannot be exploited in a genetic improvement program. No information is presently available about differences among families in energy content per oven-dry pound. However, most of the effect of type of planting stock and family on energy yields will probably be expressed through total dry matter production per acre. As seen in Table 7, the type of planting stock had a slightly greater effect on dry matter and energy yields than family. However, both effects were large. The best type of planting stock (whole seedlings) from the best family (F2) provided yields that were 1.5 times greater than the average yields from the overall study and six times greater than yields from the poorest combination of family and type of stock (top cuttings from family 'A2').

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